The transit of Mercury 2016 and the solar diameter: new opportunities after the Venus Transit

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Angular velocity and timing for eclipses and planetary transits

- In the Guidelines of eclipse observations (Science in China, 2009) I recommended to observe with absolute timing accuracy all contacts t1, t2, t3, t4: why?
- Four contacts increase the statistics
  and the accuracy is $\sqrt{4}=2$ times better
- The uncertainty on ephemerides is limited to a systematic error which is reasonably the same over the few hours of the phenomenon
- For the Moon the unknown shifts in latitude and longitude are limited by the observations made either in the northern and in the southern umbral limits of the totality shadow.
- Total eclipses are better, but annular (2006 Guyana, 2005 Spain) and even partial ones (2000 Yale, 2009 Locarno, 2010 Bialkow and Locarno, 2011 Locarno and 2015 Rome and Bialkow: studies in progress) can be used for diameter’s measurements.

Exigences of symmetry

- With an observation on Southern Limit an observation to the Northern one is more than welcome (the case of Egypt 2006 with myself in S, K. Guhl in N and A. Kilcick in the centerline) the errorbar was greatly reduced (Sol. Phys. 2009)
- Venus transits: same rationale, to avoid uncertainties in delta longitude
- Athens 2004 and Rome 2004 both phases ingress and egress
- Huairou, Beijing China 2012 both phases ingress and egress
- But the delta latitude cannot be solved even with many observers: the Earth's diameter is two times the solar parallax of 8.74'' negligible for our purpose
- Is it really necessary the exigence of symmetry?

Planetary vs lunar ephemerides: precision's examples

- Lunar occultations observed by Ptolemy used to implement secular motions of the Moon in the Ephemerides: the order of magnitude is one hour of time (1800'' per 19 centuries so about 100'' per cy, with an errorbar of 6 minutes, say 180'' or 9'' per cy)
- Ancient eclipses used to correct the rotation rate of the Earth
- Observations of Mercury gathered by Le Verrier and Newcomb showed 43'' per century of perihelion precession unexplained by Newton gravity

O-C for lunar and planetary motion

- The Moon is subjected to a three body motion plus several perturbations
- The planets are subjected to a two body motion plus several perturbations: their ephemerides are simpler and more accurate than the Moon
- The eclipses are predicted knowing the motion of the Moon and the motion of the Earth (3+2 bodies)
- For the transits only Earth and Mercury (or Venus) have to be known (2+2 bodies)
- If O are the observations and C the ephemerides we can say that for the Moon they are 9''/cy, after observational corrections, for Mercury, after GR corrections 42.9'' vs 43'' observed, 0.1''/cy

SINGLE CONTACT TRANSITS (Mercury 2016)

- The errors in longitude on the orbit of the Moon are 90 times larger than for Mercury where O-C≤0.1''/cy
- Similarly we have to expect similar figures for the latitudes, and for the Moon I have experimented (Atlas of Baily Beads 2005-2009, Sol. Phys. 2009) differences below 1'' between O and C, so the requirement of symmetrical observations
- Symmetrical observations reduce the error of absolute timing (the larger component of error in longitude)
- For an accuracy of 0.01'' symmetry is not required (and not possible for latitudes) in Mercury transits with a perfect absolute timing SO WE CAN OBSERVE FRUITFULLY ALSO A SINGLE CONTACT LIKE FOR THE MAJORITY OF EUROPEAN SITES IN 2016 MAY 9

Data reduction procedures

- We reanalyzed Venus transits in view of these considerations (Sigismondi et al., arXiv 2015)
- With exact analytical formulae to extrapolate the unperturbed contact timing (by black drop)
- The final accuracy reached 9 milli arcsec of maximum error for 2004 Venus transit (estime with the two contacts)
- Similar accuracy around 0.01'' can be reached by timing the t1,t2 of Mercury with the Sun on next transit

Velocity of the ingress

- From ephemerides we have the ingress' duration
- It corresponds to the time needed by the diameter of Mercury to enter completely in the photosphere from the Auwers' standard diameter, this gives the angular radial velocity v.r.''
- The difference between the observed timing (extrapolated from the fit with the analytical formula) and the calculated one, is ΔT
- The product v.r.''x ΔT after the reduction at 1AU is the correction to the Auwers' standard solar radius of 959.63'' used in all ephemerides

Suggested requirements for amateurs/pro

- The best instrumental characteristics are the ones of your telescope at home ☺
- But if we can obtain a longer focal length e.g. with a 3x Barlow… we exploit better the CCD pixels, because Mercury is only 10’’ wide
- With a larger focal lenght the FOV is narrower and it is difficult to point the correct region of the solar limb where the ingress occur (PA near 90°: exercises on finding it every day…using solar spots motion, 9 months to go…)
- Video with nice time resolution or series of timed photos (50/100 are enough during the 3 minutes ingress)
- To obtain better results **Train yourself before**;
- Sapienza University and ITIS Ferraris students will perform the data analysis after knowing your exact position (your longitude, latitude and altitude of observations)

The transit from the Americas

From Brazil the transit is fully visible in the morning

From US generally the egress is visible, and the ingress no excepted in the East Coast

Conclusions

The transit can be observed at high resolution either in space and in time

The black drop can be overcome by a good data reduction, fitting the geometrical instersections between the planet's profile and the photosphere

The possibility to obtain good values of the solar diameter in various wavelengths with only the ingress or the egress is very good, thanks to the accurateness of the planetary ephemerides, and it is worth to exploit this opportunity offered by ground-based observations